NASA/Industry

November 1994

Reusable Launch Vehicle (RLV) Technology
Development and Demonstration Program

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Operations Concept Vision and Operability Criteria Document

Operations Synergy Team

ENCLOSURE 3

Operations Concept
Vision
and
Operability Criteria
Document

Reusable Launch Vehicle (RLV) Technology Development and Demonstration Program

Operations Synergy Team

November 1994

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SUMMARY

The RLV Operations Concept "VISION"

The following is a summary of this RLV Operations Concept, developed from the President's *National Space Transportation Policy*, which directs a goal of **"reliable and affordable access to space"**. This "operations vision" was developed from experience gained during a variety of previous space transportation programs.

1. Provide a simplified, **very-highly automated** vehicle enabling **minimum periodic and repetitive maintenance** (airplane-like) and resultant short turnaround time between missions (hours, not months).

2. Strive to isolate vehicle ground processing from **dependence on facilities and GSE.** Routine, scheduled turnaround should replenish consumables only.

3. Promote **vehicle health monitoring/management** systems and self-test at a level which supplies only O&M-anomaly-related information that requires corrective action prior to next flight. Let the vehicle "talk" to the ground remotely during processing. Incorporate special vehicle engineering instrumentation only on specifically assigned technology demonstration vehicles.

4. Eliminate "flight readiness-style" vehicle recertification for every flight. Provide **aircraft-style vehicle-type certificate** for repetitive commercial flight operations

5. Design-in **performance margins** and flight hardware allowances to **eliminate processing impact**, i.e., strive to eliminate unscheduled work. Mission design and flight operations are **very highly** autonomous by design. No dedicated software maintenance function is required to support operations.

6. Reduce **operations and hardware complexity** for maximum utilization of resources and eliminate opportunity for human-induced system failures: Less "hands-on", less human error.

7. Employ near autonomous ground management planning at top levels. Focus on **automatic interactive scheduling** of flight vehicle, ground support facilities, and support logistics.

8. Adapt **minimum** standardized **payload** interfaces to assure maximum flexibility and affordability. The most affordable vehicle will be blind to payload needs; like a truck, not like a hospital life support system. Eliminate **payload impact** on the launch vehicle system infrastructure.

9. Ensure joint participation **AND** application of the synergism available between Operations, Avionics, Propulsion, Payloads, and Vehicle Design, to the preliminary architecture/vehicle-concept, and operations-development process. This entails **identification of technologies** that can enable development of a vehicle system meeting attributes of the *National Space Transportation Policy*.

10. The **role of engineering** (concept, development, and technology) during the **operational era** will be to perform **continuous improvement** and **technology advancement** for **future market driven needs**.

This **Operations Concept**, and its still-valid references, provides **VISION** to the RLV development process.

FOREWORD

This document synthesizes operations concepts and operability requirements development activities initiated during the mid 1980's through NASA and joint NASA/DOD studies such as Shuttle Ground Operations and Efficiencies/Technologies Study (SGOE/TS), Space Transportation Architecture Study (STAS), Advanced Launch Systems (ALS), National Launch Systems (NLS), Operationally Efficient Propulsion Systems Study (OEPSS), Operationally Efficient Launch Site Study (OELS), the 1993 NASA Access to Space (ATS) Study, and the 1994 DOD Space Launch Modernization Plan

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ACRONYMS AND ABBREVIATIONS

ALS	Advanced Launch System
ARC	Ames Research Center
ATS	Access to Space
BIT	Built-in Test
BITE	Built-in Test Equipment
DDT&E	Design, Development, Test and Evaluation
DoD	Department of Defense
EMA	Electro-Mechanical Actuator
GEO	Geostationary Earth Orbit
GSE	Ground Support Equipment
GTO	GEO Transfer Orbit
HEO	High Earth Orbit
KSC	Kennedy Space Center
LEO	Low Earth Orbit
MSFC	Marshall Space Flight Center
NASA	National Aeronautics and Space Administration
NLS	National Launch System
OELS	Operationally Efficient Launch Site Study
OEPSS	Operationally Efficient Propulsion System Study
OSTP	Office of Science and Technology Policy
QFD	Quality Function Deployment
RLV	Reusable Launch Vehicle
RLVTD&D	RLV Technology Development and Demonstration
SGOE/TS	Shuttle Ground Operations Efficiencies/Technologies Study
SPSG	Space Propulsion Synergy Group
STAS	Space Transportation Architecture Study
STS	Space Transportation System
TBD	To Be Determined
TBS	To Be Supplied
VHM	Vehicle Health Management

1.0 INTRODUCTION

1.1 Purpose

The purpose of this document is to provide the Reusable Launch Vehicle (RLV) Technology Development and Demonstration (RLVTD&D) Program with an synthesized operations concept and set of criteria for measuring operability characteristics of proposed technologies and vehicle concepts. The concept and criteria will provide the relative measure of return on investment of proposed RLV technologies and concepts with respect to reduction in operations cost or increase in operability.

1.2 Scope

This document provides Top Level requirements for the RLVTD&D Program. This document is not a traditional vehicle operations concept document. Appendix B provides a strawman outline for the subjects which would be included in such a vehicle operations concept defining the support required of a selected architectural approach.

The RLV program has not yet progressed to a maturity of concept selection. Vehicle design concepts and operations concepts must be developed in conjunction with one another including the necessary tradeoffs and analyses to ensure a desirable architecture will result.

This document defines the attributes of an operational system which should result in achievement of the RLV Program goals and requirements. All proposed technologies and vehicle configurations will be assessed for compliance with and application of the concepts and criteria herein. Technologies and vehicle configurations which do not promote an increase in operability as measured against the content of this document will not be recommended for further study, development or demonstration.

1.3 Documentation

1.3.1 Applicable Documents

National Space Transportation Policy, The White House, Office of Science and Technology Policy (OSTP), August 5, 1994

Reusable Launch Vehicle (RLV) Technology Development and Demonstration Program Plan, National Aeronautics and Space Administration (NASA), Space Access and Technology Office, Draft 2.0, August 18.1994

1.3.2 Reference Documents

Access to Space Study, Advanced Technology Team (Option 3), Final Report, Volume I: Executive Summary, and, Volume IV: Operations Plan, July 1993

1.4 Program Level Requirements

This section is a compilation of the requirements, goals, ground rules and assumptions which have been agreed to as the basis of the RLVTD&D Program. The RLVTD&D Program is a technology program not a launch vehicle program. There is, however, a vehicle definition framework within which these technologies must be applicable. For this reason, a presupposed set of RLV program definition requirements, goals, ground rules, and assumptions serves as this framework for the RLVTD&D Program technology evaluation. All operability criteria and requirements contained in this document are constrained only by the content of this section.

1.4.1 RLV Technology Development and Demonstration (RLVTD&D) Program Requirements and Goals

The overall goal of the RLVTD&D Program is to bring the technologies required for next generation reusable launch system to a demonstration in relevant environments. All technologies are being demonstrated with the objective of dramatically reducing the operations cost of future launch vehicles.

NASA's technology requirements as derived form the National Space Transportation Policy are:

- **Affordability**
  - Reduced Space Transportation Operational (recurring) Cost for Both the Existing and Replacement System
- **Reliability**
  - Improved Dependability/Reliability of Existing and Replacement System and also Improves Availability
- **Responsiveness**
  - Improved Supportability, Maintainability and Launch on Demand Availability
- **Operability**
  - Improved Operability-Simplicity
- **Safety**
  - Improved Vehicle and Personnel Safety

NASA's technology program as derived from the National Space Transportation Policy is:

- **Reusable Single-Stage-to-Orbit Concept for Replacement Space Transportation System**
- **Sub Scale Technology Demonstration Decision by December 1996**
- **Significant Private Sector Role in Planning and Evaluating Launch Technology Activities as well as Managing the Development of a New Reusable Space Transportation System**

1.4.2 RLV Program Requirements

This section is a compilation of previously defined RLV Level I Requirements. These vehicle program requirements preceded the National Space Transportation Policy release, and as such, have been evaluated for applicability to the RLVTD&D Program as defined by this policy.

The RLV Level I Program Requirements as agreed to by the MSFC RLV Study Team and presented to Industry in April 1994 were rewritten and presented to the combined RLVTD&D Program Synergy Teams at Ames Research Center (ARC) in August 1994. The following captures the content of these Level I Requirements

- **Satisfy the National Launch Needs**
- **Provide High Degree of Reliability and Passenger Safety**
- **Achieve Major Reduction in Life Cycle Costs**

- **Environmentally Acceptable**
- **Commercial Launch Needs (Required to Achieve Industry Cooperative Aquisition Agreements)**

1.4.3 RLV Program Goals, Ground Rules and Assumptions

Many RLV Program goals, assumptions and ground rules have been formulated and proposed by various teams and working groups. In some cases these statements are in conflict with the requirements stated above and in many instances are in conflict with each other. In fairness to the authors, many of these goals, ground rules and assumptions were derived prior to the release of the National Space Transportation Policy and without insight into the definition processes taking place within the other working groups and synergy teams.

In any case, since many of these statements drove to further refine the top level program requirements above, they also necessarily narrowed the concept definitions which could meet the requirements. Many of these proposed goals, ground rules and assumptions could be categorized as: 1) Functional Requirements; 2) Attributes; 3) Constraints, or; 4) Design Solutions.

To eliminate further specification of any resulting design concept, we have chosen to not repeat any of these statements here. We have chosen instead, to provide a "visionary" framework within which to evaluate proposed vehicle concepts through analysis of derived and potential operations approaches and concepts. Vehicle and operations concepts which reach farther toward this vision can ultimately be supported with significantly reduced costs.

2.0 RLV OPERATIONS CONCEPT

2.1 Background

The Access to Space Advanced Technology Team (Option 3) performed extensive background investigation into the driving factors and approaches for reducing the cost of space launch operations. They developed four cornerstones of a reduced cost approach. These are:

- Define the mission narrowly to transportation only.
- Apply modern technology to design a simple vehicle with less complex subsystems and fewer elements.
- Avoid flight-by flight certification through a prototype flight test program
- Adopt a management philosophy that empowers individuals to replace today's philosophy of decision by committee.

In further investigations to develop these concepts in more detail the Access to Space Advanced Technology Team analyzed the SR-71 aircraft, tactical aircraft, intercontinental missiles (air and sea based), advanced commercial aircraft and experimental vehicles to develop a benchmark for space launch programs. The following represent the lessons learned from these bench mark program investigations.

- Successful programs have separated development from operations.
- Simpler vehicles are more reliable.
- Fleet certifications are better than flight certifications.
- Mission surety does not require huge manning.
- Designed in operability reduces manning required to prepare sophisticated vehicles for flight.
- Mature and reliable vehicle health management systems do exist and are critical for:
  - Monitoring system performance in exotic environments.
  - Reducing the need for extensive testing.
  - Expediting ground processing.
- Individual responsibility and empowerment leads to lowered operations manning
  - a non-touch to touch manpower ratio of 3:1 is completely adequate to operate high technology aerospace equipment with confidence.

2.2 Vehicle Operations Concept

- Mission, vehicle design, fleet size, operational timelines, facilities, equipment and manpower must be developed in conjunction with each other (not as groundrules, assumptions or requirements) in order to arrive at a program with optimized cost, capability and performance.
- Development should be focused on the productivity of a single vehicle within a fleet size which is unspecified.
- The dependence of the vehicle on facility and GSE architecture should be at a minimum (e.g. single site bare pad/runway).

- Ground activities between flights should be required only to replenish consumables and install cargo.
- Autonomous vehicle capabilities should confirm vehicle condition during and between flights with no physical contact to relay status to a spaceport control capability.
- The spaceport provides consumables servicing and cargo handling services, as well as landing, taxi and take-off flight planning and monitoring (air traffic control) on a routine basis.
- Commercial aircraft-like vehicle certification for repetitive commercial flight operations should be achieved to free the system from test range constrained operation.
- The spaceport provides off line maintenance capability on an as needed basis.
- Non-touch to touch manpower ratio of less than 3:1.
- Empowered management: program manager during development, crew chief during ground operations, flight manager during flight operations.

2.3 Payload Operations/Accommodations Concept

The needs of payload customers must be taken into consideration for any commercially-operated RLV venture to compete successfully in the launch services market. On-time departure (launch) is of paramount importance to customers. The payload should be transparent to the vehicle (any available vehicle in the fleet should be able to launch any payload). Based on lessons learned from processing both shuttle and ELV payloads, the following items are for consideration for arriving at affordable customer needs.

- A standard set of essential, simplified payload interfaces with autonomous validation capability will be provided. Special requirements will be accommodated by the payload using the standard vehicle interfaces.
- The payload and vehicle integration process should be standardized and highly automated.
- Vehicle and ground system designs should minimize impacts to payload design and operations due to changing orientations and load axes.
- Ground facility and equipment requirements for standalone payload processing should not be driven by vehicle concepts.
- The vehicle and corresponding operations concepts should be defined such that payload access or passenger ingress/egress accommodations are not a significant operational issue.

2.4 Mission Design and Flight Operations Concept

Mission design and flight operation is autonomous by design. After loading-in the target orbit and the stay time, a computer designs trajectories and determines timelines for orbital maneuvers, deorbits, etc. This is possible because the vehicle will perform a set of standard tasks--payload delivery, rendezvous and dock, stay on station for some length of time, and return to any launch/landing spaceport. Any unique tasks for a mission will be handled by the payload. There will be very limited payload-vehicle interfaces. The need for various interfaces will be subject to a trade when identified. The payload assumes the responsibility to perform self test/checkout to verify its functional integrity prior to deployment from the RLV and communicates to the control computer if it is to remain on-board for the return flight.

Flight operations are automated. Generation and verification of an ascent trajectory that satisfies vehicle envelopes is automatic. Autonomous communication with the ground weather station yields day of launch ascent and landing site winds for a computer program that makes automatic go/no-go decisions. The computer informs the ground control tower of go/no-go status. The extent of the automated computer work to be done on-board the vehicle, versus on the ground, is subject to a trade, with the lowest operating cost the determining factor.

The vehicle is robust in minimizing the need for redundant hardware required for reliability. Where fault tolerance is necessary for reliability, the vehicle automatically detects and reconfigures. Navigation is onboard and autonomous, except for nearby GPS transmitters providing data during the rendezvous and approach and landing phases. GPS operation during ascent transmits position data to avoid use of range safety radars. Relative GPS is used during rendezvous. There is no dedicated software maintenance function required to support operation.

The vehicle is automated with respect to abort mode recognition, rendezvous and dock, deorbit, sequencing, and reconfiguration of vehicle systems. Vehicle robustness provides the capability to always abort either to any launch/landing spaceport or to orbit if necessary. The only uploads from the ground that involve human interaction are mode commands, such as "perform collision avoidance maneuver" or notifications due to unusual ground system failures. These communications are from the ground control tower. The determination of these commands is automated, given a human mode change decision when necessary. Autonomous uploads consist of items such as landing site weather data and occasional uploads of rendezvous-target state vectors. Failed docking attempts with the Space Station are handled automatically. The vehicle station-keeps in close proximity to the Space Station.

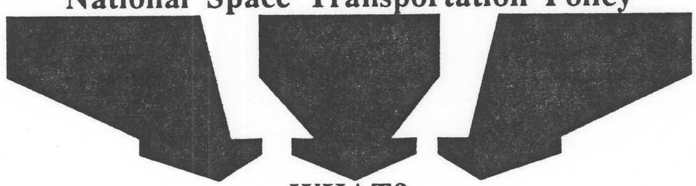
3.0 OPERABILITY CRITERIA

3.1 Background

In order to measure the capability of technologies and vehicle concepts to support or implement the preceding operations concept, some criteria must be provided against which the technologies and vehicle concepts may be relatively measured. The measurable criteria that follow were derived from similar criteria developed by the Space Propulsion Synergy Group (SPSG). A strategic, top-down approach was used. Beginning with the National Space Policy, a series of "Attributes" were determined. These were qualitative descriptions of "What" needed to be addressed in order to respond to the Space Policy.

WHY?

National Space Transportation Policy



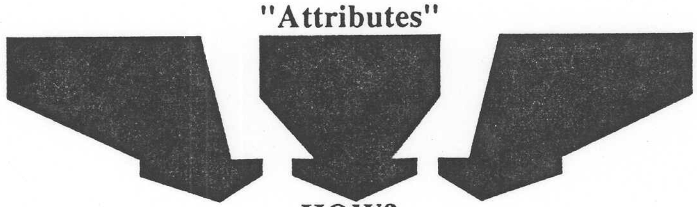
WHAT?

"Attributes"
Affordable, Dependable, Safe, Environmentally Compatible, Responsive, Low Development Risk, Public Support

Sub-attributes were also determined. For example, affordability has recurring and non-recurring costs as sub-attributes. The sub-attributes were weighted, prioritized by the need to improve that sub-attribute.

WHAT?

"Attributes"



HOW?

"Measurable Criteria"

For example, a couple of measurable criteria related to the attribute "Dependability" are "Number of potential leakage sources" and "Number of different fluids in a system."

The measurable criteria were then scored using a QFD process. For example:

1 - possible relation 3 - some relation 9- strong relation	Measurable Criteria Number of separate systems Number of . . .
Attribute Dependable Sub-Attribute Launch on time (weight = x)	How related is the Number of separate systems to launch on time?

In this way, the criteria "most related" to the attributes were determined and could be listed in prioritized order. The criteria end up weighted according to score

The measurable criteria can then be used to evaluate efforts toward improving the attributes. The technology, for example, that scores well against all the criteria has the greatest likelihood of improving the higher level strategic attribute, because the criteria are so related to the higher level attributes.

1 - possible relation 3 - some relation 9- strong relation	Measurable Criteria Number of separate systems Weight = x Number of . . .
Technology Candidate (a) Quad Propellant Engine (b) . . .	How related is this effort to the number of systems?

A comprehensive discussion of launch vehicle attributes and systems consensus from nationwide contributors to the *Space Propulsion Synergy Planning Support Working Panel* is presented in Appendix A. Scope of the input encompasses far more than propulsion.

3.2 How to Apply Criteria

Notably, even though the measurable criteria are "Hows", they are broad, generic and still very high level compared to "Hows" in the traditional sense. For example, ":minimizing the number of different fluids" is higher level than "no hypergols" which in turn is still higher level than "use EMAs for gimbaling which is a possible design.

Higher (lower numbers) criteria may include attributes of lower (higher numbers) criteria, as in this example. This has a tendency to make the list appear redundant when it is not. What really occurs is attaining higher criteria means sometimes attaining other lower level criteria automatically. As the criteria number increases, the expected potential returned improvement decreases. As a general rule of thumb, the Criteria 1 has twice the payback of Criteria 10 which has twice the payback of Criteria 20 and so on. Thus a technology that scores high marks for Criteria 3 has potentially twice the payback of a technology that scores high marks for four of the criteria above Criteria 25.

3.3 The Operability Criteria

These criteria deal with increasing operability by providing reduced operations, maintenance, manpower, equipment in increased productivity. How much will the resulting reductions, increases and ultimately cost savings be affected by these criteria is dependent on the degree to which the criteria are met. The criteria present little quantitative values but provide great qualitative metrics with which to evaluate design concepts for capability of meeting the operations concept of the preceding section.

The criteria have been split into those which endorse a minimization of specific attributes of vehicle design and those advocating maximization of characteristics as opposed to just a numerical listing.

RLV Design concepts should MINIMIZE:

1) Separate system/subsystems within the Space Transportation System.

2) Potential fluid leakage sources.

3) Hands-on activities required to handle, assemble, checkout, service, and launch.

4) Different fluids used in the Space Transportation System (Flight and Ground).

5) Active components required to function - - including flight operations (Flight and Ground).

7) Active systems required to maintain a safe vehicle.

8) Systems that require monitoring because of hazards.

9) Hazardous subsystems requiring corrective action to safe.

12) Element to element interfaces requiring engineering control.

13) Hours, special tools, and GSE for turnaround for re-flight.

15) Purges (Flight and Ground).

16) Toxic fluids.

17) Hours to refurbish the system.

19) Confined spaces on the vehicle requiring safety control.

21) Pollutive/toxic materials.

22) Physically difficult areas to access.

23) Active conditioning requirements for hardware function.

24) Checkout required.

25) Time to access a check point/points.

26) Inspection points, but easy access for those required.

27) Criticality one failure modes.

28) Quantity of pollutants (based on regulations).

29) Manufacturing/test/operations facilities (minimum total infrastructure).

30) Separate systems required for thrust vector control.

32) Countdown fluid servicing time with minimum complexity and emergency safing procedures.

34) Energy release from unplanned reaction of propellants for safety reasons.

35) Cost per day of delay of launch.

RLV Design concepts should MAXIMIZE:

6) Components with demonstrated high reliability (0.999...).

10) Percentage of totally automated systems.

11) Systems with BIT/BITE.

14) Systems with fault tolerance when reliability of hardware is not sufficient to support adequate safety of both hardware and personnel; however, emphasis should be placed on increased hardware reliability to provide this solution.

18) Mean time between major overhaul of system or its components.

20) Technologies with readiness demonstrated prior to program development start.

31) Thrust level margin.

33) Mass fraction margin.

36) Engine chamber pressure margin.

APPENDIX A

Reusable Launch System Operational Concept
- Attributes of the "Vision" -

The top level strategic plan, noted by the *Space Propulsion Strategic Planning Support Working Panel*, is intended to provide direction for propulsion technology and system development so the United States can achieve reliable and affordable access to space. The President's *National Space Transportation Policy* directs NASA and the industry to concentrate on developing technologies and system capabilities from which a resilient and cost effective space transportation infrastructure can be forged. RLV is a potential keystone of that infrastructure. It has the opportunity to be the first truly affordable space transportation system through its potential for greatly simplified ground processing and increased launch rate enabled by innovative vehicle architecture.

1.0 Mission Requirements

Mission requirements and relative capability for launch vehicles are usually stated in terms of pound of payload to low Earth orbit. For ground operations purposes (and overall program planning) the life cycle cost is of paramount interest. This approach requires a look not just at payload size and cost to orbit a pound of payload, but the cost to orbit pounds of payload per year. Launch rate, and the resultant cost per launch, is thereby factored into the data and "levels the playing field" among different vehicle concepts.

2.0 Attributes

The attributes are goals for vehicle/system characteristics desired by the customer. In the case of launch vehicles, two customers are defined. The first is the payload owner who wants the payload delivered to a specific Earth orbit. Several types of payload owners are considered. They are military, civil (NASA/scientific), and commercial. They all want the same attributes, however, each one stresses attributes somewhat differently. The military emphasizes launch on demand, while the civilian agency stresses safety, reliability, and environmental acceptability . The commercial owner stresses operating cost because of competition from foreign launchers. The second "customer" is the system operator engaged in checking out, maintaining, and launching the vehicle. This customer stresses system operability to maintain a viable and robust launch program and to keep the operating costs under control.

The RLV program is a promise to integrate Operations concerns into the initial and developmental design activities.

Summarizing in more detail:

Military stressed:
- Launch on demand
- Low operations cost
- High reliability

Commercial stressed:
- Competitive edge - derived from the above same characteristics

Civilian agency stressed:
- The same above items plus safety and environmental acceptability

System operator (launch site):
- "Wants it all" with emphasis on operability - quick turnaround

A set of launch vehicle and systems attributes (Table 1) was developed during 1992 by the *Space Propulsion Strategic Planning Support Working Panel.* Scope of the documented results of their deliberations have operational impacts far greater than "mere propulsion".

Once the attributes were established, they were ranked in priority of need for improvement and assigned weighting factors. The factors were based on the working panel attendee's estimate of the importance of each attribute, and on present status and planned improvement as envisioned by the supplier.

As can be seen from the above discussion, transportation system requirements vary widely and can be satisfied by different technological approaches. The common threads that run through all space transportation system requirements are affordability, reliability, and operability. They can be more precisely expressed by a series of system attributes described in the following section.

Table 1

LAUNCH VEHICLE AND SYSTEMS ATTRIBUTES

AFFORDABILITY
- Low recurring cost
- Low non-recurring cost

ENVIRONMENTAL COMPATIBILITY
- Minimum effect on atmosphere
- Minimum environmental impact at all sites

SAFETY
- Personnel safety
- Vehicle safety
- Equipment/facility safety

DEPENDABILITY
- Intact vehicle recovery
- Mission success
- Launch on time

RESPONSIVENESS
- Flexibility
- Capacity
- Vehicle health management
- Easy vehicle integration
- Maintainability
- Simplicity
- Launch on demand
- Easily supportable

LOW DEVELOPMENT RISK
- Technology options
- Technology readiness
- Technology margin

PUBLIC SUPPORT
- Beneficial to GNP
- Social perception

2.1 Affordability

Affordability is determined by both the recurring (operational) and non-recurring (development and production) costs. Operational costs include flight hardware and GSE, sustaining engineering, launch support facilities O&M, and mission management and control. Development and production costs include "establishing infrastructure", i.e., facilities and tooling as well as the first few sets of hardware supporting the development phase. Both recurring and non-recurring costs are reduced by system simplicity and standard materials and components. Previous KSC studies (SGOE/T) have shown reduction in system quantities provides an exponential payback in program cost reduction ; recurring AND non-recurring.

In addition, recurring cost will depend upon operability. The present operating cost, or the cost of placing one pound into low Earth orbit, varies from $3000 to $20,000, depending on the launch vehicle and the loading factor used. One of the goals set by the *Space Propulsion Synergy Group* is to reduce this number to $500 per pound to be competitive with the rapidly developing space transportation capabilities of countries such as China and India.

It is interesting to note, in comparison, the 1991 *AIAA International Reference Guide to Space Launch Systems* reports the Russian two-stage, lox/kerosene Zenit is expected to deliver a 34,600-lb payload to 12 deg. Earth orbit from Cape York, Australia at a projected launch cost of $70M; $2023 per pound.

A vision of RLV affordability, with the new focus on industry participation, will hinge entirely on establishing U.S. Government agencies as providing technology R&D financing AND establishing them as "anchor tenant customers". Industry WILL NOT be able, or willing, to develop large fractions of risk capital unless an acceptable return-on-investment is clearly evident.

2.2 Environmental Compatibility

Environmental compatibility is mandated by U.S. Federal and local law. The usual primary consideration is environmental impact of exhaust products. However, concern for the environment deals with any unwanted emission into the air and waste management for ground and water protection at all locations involved in manufacturing, test, assembly, and launch. A secondary consideration is the environmental impact of commodity leakage from flight hardware during processing and countdown.

An example of usually ignored environmental impact to the aerospace infrastructure is the severe ecological impact noted at the Louisiana site of hypergolic propellant manufacture. Trees are reportedly dead or dying for some miles around the plant. USAF has dedicated several million dollars to enlarged storage facilities at CCAFS to counter or minimize potential loss of that source. Interstate highway transportation of hypergols is also a hotly contested safety and environment issue.

An example of this impact is that KSC launch sites 39-C and D, identified many years ago for potential future development north of Pad B (and into Mosquito Lagoon), are very unlikely to ever be approved. These areas cover white and brown pelican rookeries, and charted bald eagle nesting areas; not to mention the 15 other federally-identified endangered species of birds, snakes, and mammals.

2.3 Safety

Personnel death is catastrophic, whether flight crew or ground support persons. Closed compartments and inert gasses, traditionally employed to "safe" these volumes, pose a large threat to personnel safety as well as the toxic and flammable substances. KSC and CCAFS have experienced fatalities due to suffocation, ignition of propellants, explosion of high pressure devices, and crippling injuries from toxics.

Flight crew safety is directly related to the reliability issue. Crew and vehicle safety deals with minimizing the risk of possible catastrophic failures during flight, and toxic leakage or ignition during ground handling. Catastrophic failures tend to be structural failures. Structural margins have the potential to passively avoid catastrophic failures; however, more complicated elements, such as bonds and coatings, may have more difficulty in providing the desired margin. Destructive potential, such as the pressure and volume for pressure vessels and the rotational rate of turbomachinery, should be minimized. Active avoidance of catastrophic failures by detection of incipient failures and performing a shutdown is an additional consideration. Ability to separate propellants from ground personnel will be the main concern for ground handling safety.

2.4 Dependability

Dependability is the ability of hardware to perform when needed, from its arrival at the launch site through mission completion. Another synonym here is reliability. Probability of intact vehicle recovery, or of mission success, will depend on the simplicity and robustness of propulsion and vehicle systems at every level. Simplicity is improved by reducing the quantity of propulsion systems, subsystems, components, and component features. However, complexity of analysis, manufacturing, and operating the remaining items must be considered.

On the vehicle level, robustness means providing an ample performance design margin. On the component level, robustness means providing design margin for various types of burdens (such as structural loads, contamination, and off-nominal load directions). Improved simplicity and robustness will also improve the other attributes. On the flight-critical systems level, robustness means the ability to operate with failures, usually through hot spares or built-in redundancy. However, redundancy will usually be detrimental to the other attributes because it rapidly creates additional ground processing workload for test and checkout/verification. A useful exception to this observation is power circuit redundancy used in Peculiar Support Equipment (PSE) used for test and checkout which can reduce false failure indications and the resultant induced re-testing requirement.

For these discussions "dependability" includes consideration of availability:

<u>Availability</u>

Availability is the probability of launching on schedule, or more precisely, within 12 hours of scheduled time. This means that vehicle anomalies do not require delaying the launch by more than 12 hours. For propulsion systems, availability is the product of component reliabilities. Propulsion systems redundancy is not a benefit, since the criticality of propulsion components and lack of performance margin normally requires that all are operational prior to launch.

Another factor of "availability" often overlooked is the major attribute of component accessibility for inspection, maintenance , repair, or removal and replacement. In October 1989 removal and replacement of SSME 2030 engine controller at Pad B for STS-38 required four full days (12 shifts) from the point of decision. This was a day-for-day delay in launch schedule which impacted all succeeding launch schedules. Much of the time was expended in preps for, and removal/replacement of, sophisticated heat shielding and specialized component handling GSE. In an R&D test stand scenario, where access is not hampered by flight-type insulation, closed aft end, specialized GSE, and stringent documentation, this activity would have taken no more than two shifts.

2.5 Responsiveness

Responsiveness is the calendar time required to respond to a customer's request to fly a mission, prepare the vehicle for launch and perform launch operations. Responsiveness requires the same propulsion system characteristics as operability. Present goal for future programs is to reduce responsiveness time to seven days.

Presently, SSMEs are routinely removed at the OPF and sent to the Vehicle Assembly Building (VAB) SSME shop for inspection and servicing. This activity occurs mostly "offline" from Shuttle ground preparations, and requires a period of 15 days. This recent change in process has removed the previous processing schedule "tent pole" which was created by serial processing of the engines. This has contributed to improved Shuttle flow rate, but is still a significant cost element of operations.

The OEPS Study performed by Rocketdyne has shown an innovative, integrated modular propulsion concept that allows normal flight to require engines and components to operate at 80% rated thrust level. An "engine out" anomaly is countered by increasing performance of the remaining components to 100%;

producing a successfully completed mission. This method of operation, and attention to reliability factors, can be expected to greatly improve engine life and allow "robust turnaround" with greatly reduced requirements for refurbishment and revalidation for flight. Any future rocket-propelled space transportation vehicle concept study, should examine and assess this propulsion concept. The performance, operability and system component statistics are impressive and promise to provide performance margin and operability so prominently missing from "conventional" propulsion systems.

The terms *"flexibility"*, *"capacity"*, and *"operability"* are also discussed here under the broad heading of "responsiveness"

Flexibility

Flexibility is the capability for timely response to meet changing or evolving customer requirements. This is a very strong characteristic that must be incorporated in the RLV concept, with increased flight rates, and rapid potential turnaround. Flexibility is also theoretically enhanced during a maturing program by modifications enabling a broader range of performance and/or payload accommodations.

Capacity

Capacity is the ability to meet multiple customer requirements such as launch window, payload size and weight, number of launches, launch rate, and payload destination. For a medium size payloads system, capacity is specified as 500,000 pounds per year delivered to low Earth orbit. With a given launch infrastructure it determines the required annual launch rate. Launch rate, in turn, depends upon the amount of ground operations required, ease of manufacture of expendable vehicles (where used), and quantity of ground facilities.

Operability

Operability basically reflects the number of man-hours required to check-out, maintain, and operate the vehicle and supporting systems, plus logistics. Besides simplicity, supportability, and robustness, operability will depend upon ease of access, modularization, automation, and ease of vehicle integration. However, beware of "over-integration" at the systems level. The Shuttle orbiter hydraulic system is an example. The entire vehicle hydraulics are interconnected. Consequently, much ground processing productivity is lost during hydraulics start and component actuation when technicians performing a wide variety of work unrelated to hydraulic systems must leave the vehicle for safety reasons.

Operability is expressed in terms of Launch Operability Index (LOI) which ranges from 0 to 1. The LOI is a specific measure of effectiveness determined for a particular launch vehicle in accordance with the methodology developed in KSC's Operationally Efficient Propulsion Systems Study (OEPSS). Improvements in LOI of future vehicles is based on minimizing or eliminating the impact of 24 specific operational concerns identified by the OEPSS (see Appendix B, tailored for RLV).

2.6 Low Development Risk

Development risk can be viewed in terms of probability of developing the system within schedule and cost constraints. Availability of multiple technologies demonstrated beyond laboratory, and up to full scale, component level (in relevant environments) will increase probability of a successful development program.

2.7 Public Support

Public support is usually derived from two sources: positive economic impact on a segment of population, or a positive social perception by the majority of the population. A highly visible, strong commercial launch market would be an example of the first. Establishment of a successful lunar outpost would be an example of the second.

APPENDIX B

Strawman RLV Operations Concept Outline

1.0 Purpose and Scope

1.1 Program Elements
- Describe the launch vehicle, ground infrastructure, and launch control system.
- Describe the payload community interface

2.0 Program Requirements Overview

2.1 System Objectives
- Low cost access to space
- Describe reliability, robustness, and other objectives

2.2 Program Requirements Summary
- Cost goals, turnaround requirements, and other requirements of the program
- Summarize all Level I and Level II requirements

3.0 Launch Operations Concept

3.1 Launch Site Selection and Orbital Capability
- East and west coast site(s) selection options
- Existing launch site/infrastructure vs. all new site requirements
- Orbital capability from the selected site(s)

3.2 Launch Processing Concept and Schedules
- Flow diagram and description of the tasks required for launch and recovery
- Allocated processing schedules for the processing steps described above

3.3 Launch Facilities, Ground Support Equipment, and Transportation
- Description of the facilities, GSE, LSE, and TSE
- Identification of modifications to the existing infrastructure (with ROM cost)
- Identification of new infrastructure with ROM cost
- Supplement the description in 3.2 if required to show the use of the facilities

3.4 Pad Operations, Propellant Load System, and Vehicle to Ground Interfaces
- Detailed allocated timeline and description of the pad operations
- Description of the propellant load system, new or modified, cost, capabilities
- Description of the umbilicals, gas, electrical, and other interfaces
- Description of payload provisions and interfaces at pad

3.5 Launch Control System
- Description of the launch control system
- Launch commit criteria
- Launch team duties and description
- Payload monitoring requirements

3.6 Range Interface and Landing Operations
- Range safety documentation and control
- Autonomous landing commit criteria
- Selection of landing site
- Ground support of landing operations

3.7 Post-Flight Processing
- Vehicle safing functions
- Payload removal (if required)
- Return to launch site operations (if required)
- Contingency landing provisions (if required)

3.8 Operations and Maintenance Concept
- Reliability engineering concept
- Logistics support requirements
- Maintenance database, planning, and monitor system

4.0 Mission Operations Concept

4.1 Mission Characteristics and Phases
- Overview of each phase of a typical mission from launch to landing

4.2 Flight Control and Ascent Characteristics
- Telemetry links and control
- Nominal ascent phases

4.3 On-Orbit Operations, Re-Entry, and Landing
- Payload deployment operations
- Attitude control
- Re-entry operations
- Landing operations

4.4 Abort and Mission Contingencies
- Launch abort operations
- Turnaround processing and timelines
- Ascent abort phases
- Mission contingencies

5.0 Payload Accommodations

5.1 Payload Bay Characteristics and Environments
- Payload bay dimensions and accommodations
- Payload interfaces, environment, and capabilities

5.2 Payload Processing Concept
- Horizontal vs. vertical processing
- Standardized interfaces
- Allocated timelines and schedules
- Facility requirements

5.3 Payload Integration and Checkout
- Facility and GSE requirements
- TSE requirements
- Facility and vehicle interfaces
- Allocated schedules

5.4 Payload Health Status, Communication and Control
- Power, fluid, and environmental control system interfaces

6.0 Certifications, Regulations, and Constraints

6.1 Department of Transportation Launch Licensing
- Steps, procedures, and schedule for DOT license

6.2 Range Safety Certification and Documentation
- Range certification procedures and schedule

6.3 Operational Activation and Certification of Procedures
- Independent validation and verification (IV&V) process

6.4 Environmental Certifications
- Local, state, and federal certifications, requirements, and schedule for compliance